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Heat Pump System with Thermal Storage

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HEAT PUMP SYSTEM WITH THERMAL STORAGE

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ABSTRACT

Heat pump system room air conditioners have been widely used in Japan for residential air conditioners due to their none air polluting features and high operational safety. However, there still remain several problems to be solved. The first is the discomfort of falling in room air temperature by the interruption of heating during the defrosting operation. The second is the long start-up periods in the initial heating operation in the cold season. In order to solve these problems, we have successfully developed a new system of heat pump air conditioners with thermal storage. A rotary compressor with thermal storage function has been newly developed having phase change thermal storage material and heat exchanger around the out side of the compressor dome.

INTRODUCTION

Because of its safety, efficiency, cleanliness, space saving characteristics, the heat pump room air conditioners have been quite popular in Japan for residential use. The past five years have seen a rapid penetration of the inverter technique to the field of heat pump. However, there are several problems mention above. In order to eliminate the defects of the conventional heat pump system, several efforts have been undertaken to develop the practical utility of the thermal storage system for heat pumps in the past. However, their applications remain quite limited for residential use.*(1) It can be attribute to the following reasons.

(1) A large installation space was required.

(2) System set up was complicated.

(3) Heating C.O.P. was reduced due to the heat loss.

In this paper we have investigated the characteristics of the heat pump system with thermal storage functioned rotary compressor, which enables to reduce the space for the thermal storage vessel for residential use, and simplified the refrigerant circuit. The product was put on the market in 1989.

OUTLINE OF THE SYSTEM CONFIGURATION

Fig-1 shows the refrigeration cycle of the system. The major components are the compressor with thermal storage function, indoor heat exchanger, outdoor heat exchanger, 4 way valve and expansion valve. A rotary compressor with thermal storage function is mounted having phase change thermal storage material and a heat exchanger around the outside of the compressor dome.

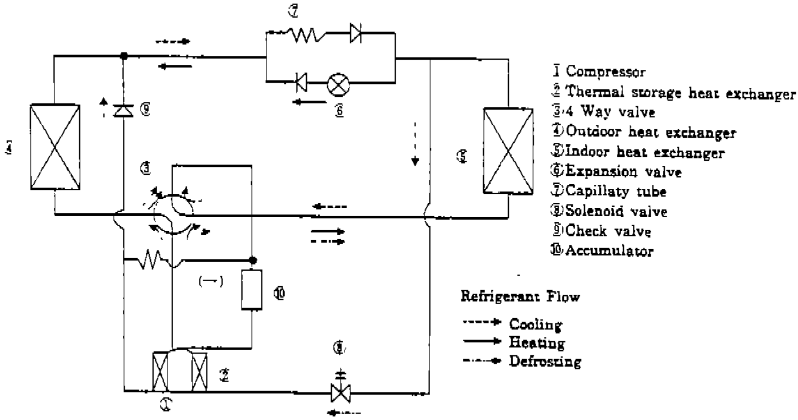

Fig. 1 Refrigeration cycle of the heat pump with thermal storage.

Fig-2 shows an exterior view and the internal structure of the compressor with thermal storage function. A finned tube heat exchanger is housed tightly with the phase change thermal storage material. Heat radiated from a compressor dome is transferred to the thermal storage material through the heat exchanger fins. Therefore the temperature of the thermal storage material approaches nearly the compressor dome temperature, so that the stored heat includes not only latent heat, but sensible heat. The thermal storage material accumulates heat during the heating operation. Heat storage vessel formed by the compressor dome and outer shell is designed structurally to be hermetic to minimize deterioration due to oxidization caused by oxygen in the air. The internal pressure of the heat storage vessel is kept to be lower than the atmospheric pressure throughout the whole of the cycle over a range of operating condition. In adding a relief valve is provided to prevent an accidental pressure rise due to the leakage of

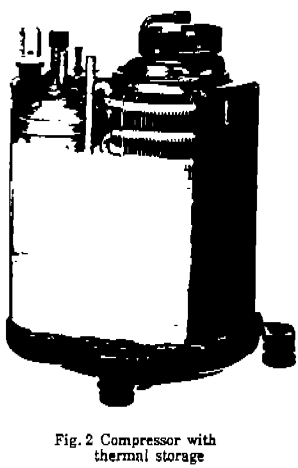

Fig. 2 Compressor with thermal storage

the refrigerant or the volumetric change of the material during the phase change which might not secure a safe void space within the vessel. In order to develop practical applications, the thermal storage material should meet the following requirements.

(1) High reliability at high temperatures.

(2) A large amount of latent heat per unit volume.

(3) Not corrosive to the material of heat storage vessels and heat exchanger.

(4) Service temperature range corresponding to the temperature in the R22 refrigeration cycle.

Considering these requirements, we investigated several applicant substances. Fig-3 shows the relationships between the temperature and the stored heat per unit volume of the major Phase Change Materials. $Na_2SO_4 \cdot 10H_2O$ or $CaCl_2 \cdot 6H_2O$ have a large amount of stored heat, but they are corrosive to some metals, and their handling is difficult for its characteristics, such as subcooling and phase separations. As a result, polyethylene glycol is most likely to meet the mentioned requirements. Table-1 shows the characteristics of polyethlene glycol the thermal storage material that we employed.

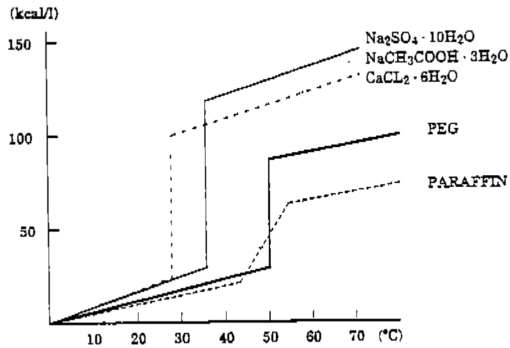

Fig-3 Amount of stored heat of the principal P C M

Table 1. Physical properties of thermal storage material

Thermal storage material	Polyethylene glycol	
Melting point temp. (°C)	54~59 (129~138°F)	
Latent heat (Kcal/ℓ)	55	
	Liquid phase	Solid phase
Specific weight (Kg/ℓ)	1.1	1.23
Specific heat (Kcal/kg°C)	0.55	――
Thermal conductivity (Kcal/mh°C)	0.11	――

PERFORMANCE OF HEAT PUMP WITH THERMAL STORAGE

This model represents the so-called split-type heat pump air conditioner which is most popular for residential use in Japan. The principal specification is shown in Table-2.

Table 2. Principal specifications

Heating	Temp. Condition	Indoor 20°C(68.0°F) Outdoor 7°C(44.6°F)	Indoor 20°C(68.0°F) Outdoor 2°C(35.6°F)
	Heating Capacity	4.2 Kw (NOMINAL) (0.5 Kw~6.1 Kw)	4.4 Kw
	Power Input	1580 W (NOMINAL) (240 W~1800 W)	1590 W
	Heating Capacity during defrosting		3.5 Kw (AVERAGE)
Cooling	Temp. Condition	Indoor 27°C (80.6°F) Outdoor 35°C (95°F)	
	Cooling Capacity	2.8 Kw (NOMINAL) (0.5 Kw ~3.4 Kw)	
	Power Input	1300 W(NOMINAL) (260 W~1460 W)	
Operating frequency range		(2 Cylinder Rotary Compressor) 15Hz~150Hz	
Power supply		Single Phase 100V 50/60Hz	

<u>Heat Storage Mode</u> The heat storage mode operation is performed during the period of heating operation by accumulating heat created inside of the compressor dome which is usually radiated to the atmosphere with the conventional system. Heat from a compressor is virtually waste heat, therefore it does not affect the heating capacity. A thermal storage is designed to have a performance of taking 30 or 40 minutes to accumulate heat on heating mode. After heating is turned off, the profile of temperature drop of the compressor with thermal storage is shown in Fig-4 by a solid line, while a dotted line represents a conventional compressor. If the temperature of the heat storage material is above the specified temperature, the system remains stopped, but when it falls bellow the preset temperature due to the heat loss to the out door air, the compressor motor is turned on with low power which is unable to rotate so that the heat storage material can be maintained at the preset temperature in preparation for the start-up heating mode. Comparatively the temperature of the compressor with thermal storage is kept high, due to the heat capacity of the thermal storage material. And the preparation for the start-up heating mode is not necessary for 8 hours after compressor stopped.

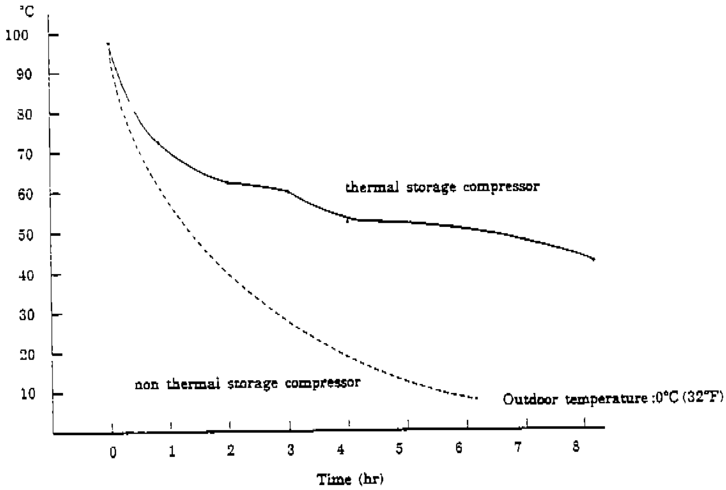

Fig.4 Profile of temperature drop of thermal storage Material after heating operation.

Start-up Mode of Heating The start-up mode of heating using the stored heat is carried out as follows.

(1) Run the compressor to recover refrigerant trapped in the out door heat exchanger. The operating frequency of the compressor can be increased rapidly because of the high temperature of the compressor due to the thermal storage material, so that the oil inside of compressor is not taken out to the refrigerant circuit. Sound power characteristics of the compressor running at high frequency is improved, due to the damping effect of the heat storage material which will be mentioned later.

(2) Open the solenoid valve provided at the inlet side of the heat exchanger attached to the compressor dome. (Expansion valve is closed at this time.)

Since the heat storage material has been already kept above the specified temperature, the compressor can be operated with a increasing suction pressure which results in the high capacity heating operation.

Heating Mode During Defrosting

(1) When the defrosting signal is given, the solenoid valve at the inlet side of the heat exchanger is opened and the temperature of the thermal storage material is sensed. The air volume of the indoor unit is dependent on the quantity of stored heat so as to perform defrosting completely.

(2) The refrigerant gas from a compressor goes through a 4-way valve into the indoor heat exchanger where heating is achieved and liquefied.

(3) The liquid refrigerant goes through a solenoid valve into the thermal storage heat exchanger attached to the compressor dome. It absorbs heat from the thermal storage material and is evaporated and super-heated. (The solenoid valve provided at the inlet side of the suction line is closed.)

(4) The refrigerant gas goes into the outdoor heat exchanger where it radiates heat to melt the frost and is liquefied. (The outdoor fan is turned off.)

Fig-5 shows this cycle in Mollier diagram. As we see from this figure, the heating capacity during defrosting is kept almost the same as that of normal heating mode.

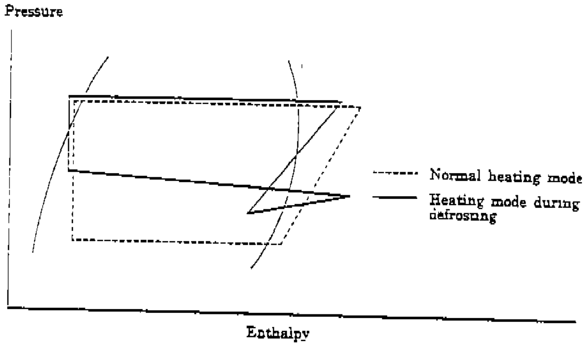

Fig. 5 Mollier diagram on heating mode during defrosting

EFFECTS OF HEAT PUMP AIR CONDITIONER WITH THERMAL STORAGE

Initial Heating Mode The rising rate of discharge air temperature achieved with this model is shown in Fig-6. A solid line represents the rising characteristics of a heat pump air conditioner with thermal storage function, while a dotted line represents a conventional heat pump air conditioner without a thermal storage function. The time required before reaching a discharge air temperature of 45°C(113°F) is reduced to approximately 50% compared to the system without a thermal storage function. A discharge air temperature of 45°C is enough for the inhabitants to feel thermal comfort.

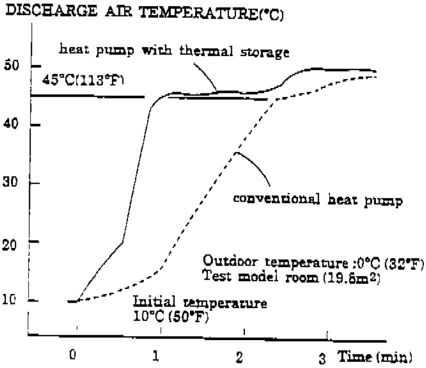

Fig. 6 Characteristics of start-up heating operation

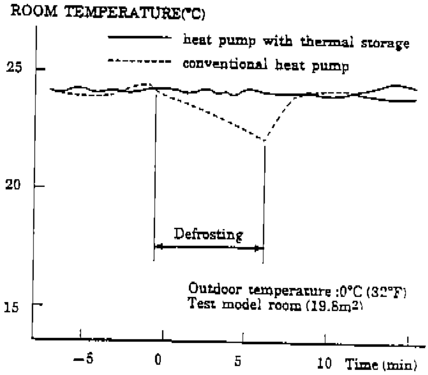

Fig. 7 Room temperture profiles while defrosting

Defrosting Performance Fig-7 shows the test results of the room temperature profiles while defrosting operation. The solid line denotes a heat pump with thermal storage and the dotted line denotes a conventional heat pump. When the thermal storage temperature is above 90°C(194°F), heating capacity of 3.5kw is available during defrosting operation. Therefore, there is hardly any room temperature drop, thus improving living comfort. The integrated heating capacity and C.O.P. in the low outdoor temperature range in which defrosting occurs frequently are shown in Table-3. The test results indicate the improvement of the operating characteristics with the thermal storage compared to the conventional system. This is the result of utilizing the waste heat from the compressor dome effectively.

Table 3. Operating characteristics at low outdoor temperature
Indoor 20°C (68.0°F)
Outdoor 2°C (35.6°F)

	MODEL WITH THERMAL STORAGE	CONVENTIONAL MODEL
Integrated Heating Capacity	4.4Kw (110)	4.0 Kw (100)
Integrated Power Input	1590 W	1520 W
Integrated C.O.P	2.77 (105)	2.63 (100)

Sound Power Characteristics of Compressor Due to the characteristics of the inverter. cycle performance has been fundamentally improved. However, more widely the inverter aided heat pump is used for residential use, the greater the problems have become of discomfort created by the compressor noise running at higher R.P.M. The configuration of newly developed compressor with a thermal storage function gives a improvement of sound power characteristics. This is mainly due to the damping effect of the thermal storage material. Fig-8 shows the test results. From this figure, it can be seen that the sound power level is improved over a range of operating conditions.

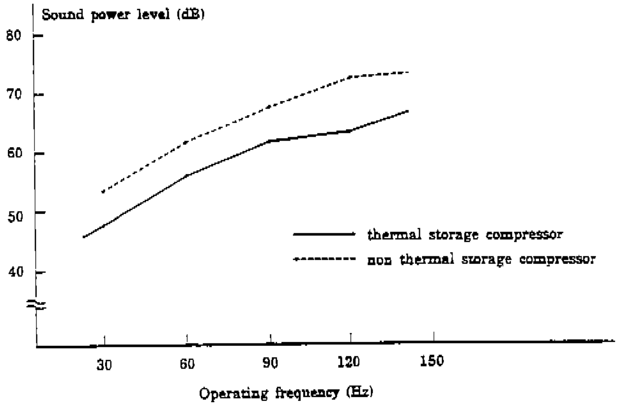

Fig. 8 Sound power characteristics of thermal storage compressor

Field Test in Cold District　In the cold season, conventional heat pump system fall into insufficiency of heating capacity caused by frequent defrosting operation and cold outdoor temperature. Especially in cold districts, like Hokkaido, a typical cold district in Japan, such problems have usually experienced, slow rising in the start-up period of heating operation, and fall in room temperature caused by the interruption of the heating operation during defrosting. We tested the newly developed air conditioner with thermal storage in Sapporo city, the central area of Hokkaido, in cold season. (1989 , october -1990 , april) Fig-9 shows the outdoor temperature distribution for a year in the major city in the world.*(2) It shows that the climate of Sapporo city seems to belong to cold districts in the world where we can use the heat pump room air conditioner effectively. Fig-10 shows the result of the field test. Outdoor temperature one day dropped below -10°C, however room temperature kept about 21°C, and moreover their discharge air temperature indicated about 40°C during defrosting.

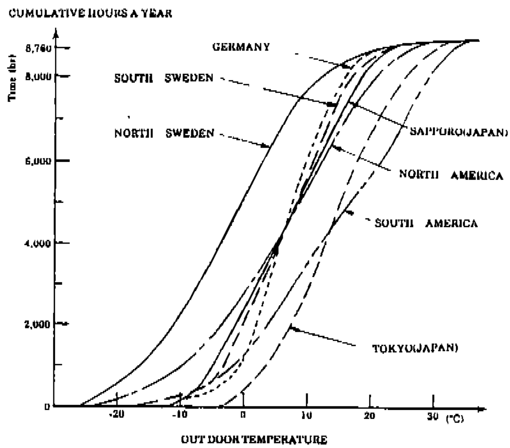

Fig-9 OUT DOOR TEMPERATURE DISTRIBUTION IN THE WORLD

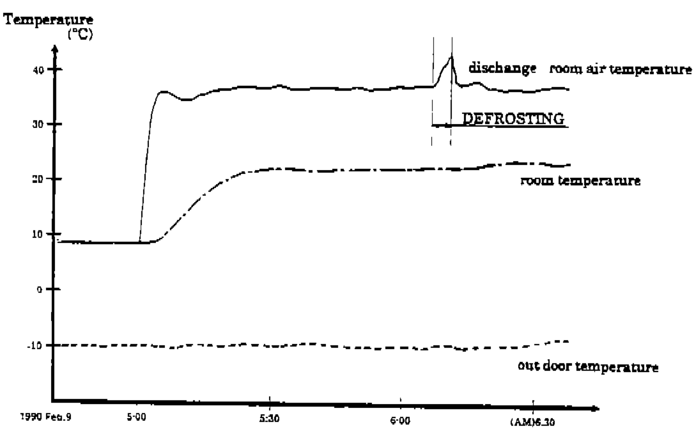

Fig-10 RESULT OF FIELD TEST

RESULTS AND FUTURE TASKS

In this paper, we described a compact and practical heat pump air conditioner with thermal storage for residential use, improving the comfort by reducing the periods of the initial heat-up operation and uninterrupted heating during the defrosting operation. They are summarized as follows.

(1) A continuous heating capacity of 3.5kw was achieved during the defrosting operation.

(2) Initial heat-up periods was reduced by half.

(3) The integrated heating capacity was improved by 10%, and the heating C.O.P. was improved by 5%, utilizing the waste heat from the compressor dome. (Especially in cold season)

(4) Noise level of the compressor was reduced by 5~9(dB).

(5) Installation space was kept the same as a conventional heat pump.

(6) Cost was kept within a reasonable range because of the simplicity of the system.

In the future, we should develop this thermal storage system in more wide range of the operation, and expand the utilization of the thermal storage in the field of heat pump.

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